

Introducing design in the development of effective climate services

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ABSTRACT

Seasonal to decadal climate predictions have the potential to inform different sectors in adapting their short to medium term practices and plans to climate variability and change. The data these predictions generate, however, is still not readily usable, nor widely used in decision-making. This paper addresses two key challenges: a **domain challenge** pertaining to an emerging climate services market, where users, tasks and data may be unknown; and an **informational challenge** pertaining to the interpretation, use and adoption of novel and complex scientific data.

The paper provides insights into the contributions design can offer to the development of climate services. We illustrate the key steps and share the main lessons learnt from our experience in the creation of Project Ukko (<http://project-ukko.net>), a fully working climate services prototype developed within the European project EUPORIAS. To address the domain challenge in climate services, extensive engagement with science and industry stakeholders was required. To address the informational challenge, we applied visualisation techniques that can help users to interpret and utilise the information as simply and quickly as possible. Fostering interdisciplinary teams of design researchers, climate scientists and communication specialists brought a wide range of expertise and competences in all stages of climate services development. Specifically, the project recognised the role of users in co-designing the product. This helped to improve the usability of climate predictions, tailor climate information to answer actual needs of users, better communicate uncertainty, and bridge the gap between state-of-the-art climate predictions and users' readiness to apply this novel information.

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Practical Implications

Recent advances in data provision from climate modelling can increase resilience of society to climate variability and change. Seasonal to decadal climate predictions deal with forecasts for future times ranging from more than two weeks to one year (seasonal) and up to 30 years (decadal). Seasonal to decadal climate predictions can inform short to medium term decisions in different sectors. This data is, however, still of a limited use and scientists are on a learning curve in their understanding of how to tailor climate information to support decision-making in different sectors, and ultimately facilitate its uptake in the industry arena. To demonstrate the potential to transform this information into useful and usable products, epitomised in climate services, this research developed a fully working prototype of a climate service to provide climate predictions tailored to the specific requirements of users in energy sector.

Climate services need to meet users' needs, capabilities and decision framings and thus collaboration with potential users from an early stage of the service design process is necessary to provide products and services that are likely to be used. The emerging field of climate services also entails an evident informational challenge. This concerns the probabilistic nature of climate predictions,

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i.e. this information gives the probability of occurrence of certain outcomes as projected by the model, rather than a deterministic, single future prediction. The informational challenge in climate services presents also the requirement to communicate and present complex scientific information to decision makers in industry, particularly considering various decision-making framings and the diversity of the needs that should be addressed. In this context, design and data visualisation are well-established fields with extensive experience in tackling informational challenges.

To put the seasonal forecast service into practice, we introduced a design research and visual design component to tackle the recognised challenges related to an emerging climate services market and complex scientific data interpretation, as well as its translation into usable and relevant knowledge. An interdisciplinary team, composed of design researchers and climate scientists, accompanied by a data designer, worked on integrating a design and visualisation approach in the development of the climate service. The result of this collaboration, which broke from a standard single discipline approach, was a climate service prototype – Project Ukko.

The Project Ukko visualisation interface provides seasonal wind speed predictions for decision makers in wind energy. It presents seasonal wind speed forecasts by using symbols that summarise different forecast parameters in the dimensions of a single line. Specifically, these lines encode prediction skill through opacity, predicted wind speed through line thickness, and predicted trend of wind speed through line tilt and colour. A multidimensional data display enables drawing the viewers' attention immediately to those spots with larger probabilities of significant changes in wind speed.

The development of Project Ukko included involvement of potential end-users throughout the climate service design and visualisation process, using different user engagement methods and deploying various communication channels. This helped strengthen the provider-user interface for the climate service.

By describing the key steps in the development of the climate service prototype tailored to the specific requirements of users, this work provides recommendations and guidelines to overcome the challenges entailed in the development of a climate service. The main lessons learnt in this process that we would like to share with climate services developers are the following:

1. The first step is to identify, through user consultation, in which areas climate predictions can improve decision-making processes and convey the utility of specific services in the effectiveness of users' day-to-day work. The early stage of the development process should be devoted sufficient time, to encompass extensive domain and task characterization and bridge the gap between the languages of experts with different fields of expertise.
2. An interdisciplinary team, bringing together scientists, users and designers, is needed to develop an effective solution to putting probabilistic information into an interface that might be used by decision makers. Interdisciplinary teams, however, need clear contexts of collaboration and sufficient learning time to develop mutual understanding.
3. Establishing an effective service provider–user interface is necessary to elicit requirements for a product that the user may previously not have considered. End-users and other relevant actors in the science, industry and design sectors should be engaged throughout all stages of the design of a climate service. Applying a variety of user-engagement methods, including conventional ones – surveys, interviews and consultations, as well as more novel ones – design workshops, interactive exhibits and festivals, can help define the problem and domain space, collect user feedback on early versions of prototypes or evaluate the final climate service.
4. Visually representing probabilistic information can entail a compromise between scientific soundness, functionality and aesthetics. A successful visual design application helps users to capture and understand the information provided by a climate service as simply and quickly as possible.
5. A well-structured dissemination and engagement strategy executed through different communication and discourse channels, as well as direct involvement of potential users in the prototype co-creation, can make more likely the penetration of a climate service in users' decision-making processes.
6. Finally, due to the complexity and novelty of the climate services field, it is not always possible to meet user expectations or fully answer their needs. Any climate service design should, however, consider and evaluate users' feedback to the greatest extent possible and adopt full co-design as a primary strategy, particularly when it comes to user interface characteristics and additional data and functionalities needed.

1. Introduction

In the last decades climate change has caused impacts on natural and human systems on all continents and across the oceans (IPCC, 2014). Socio-economic costs, associated with climate change damage and need for adaptation, are expected to escalate. Increased costs are not only related to increased frequency and severity, but also to the timing uncertainty of these extreme events (Van Alast, 2006; IPCC, 2014). Access to credible weather and climate information has the potential to improve our resilience to climate variability and change. Advances in the science behind climate predictions are creating an unprecedented potential to provide climate forecasts over the coming months, seasons and decades (Doblas-Reyes et al., 2013; Goddard et al., 2010).

Seasonal to decadal (S2D) climate predictions deal with forecasts for future times ranging between more than two weeks and slightly longer than one year (seasonal) up to 30 years (decadal)

(Doblas-Reyes et al., 2013). We are, however, still on a learning curve in our understanding of how to tailor S2D climate information to support decision-making in different sectors, and ultimately facilitate its uptake. Awareness of recent advances in S2D climate predictions and their possible applications is limited in the industry arena (Bruno Soares and Dessai, 2016; Dilling and Lemos, 2011; McNie, 2007). To demonstrate the potential to transform this information into useful and usable products, epitomised in climate services, the EUPORIAS project set out to develop fully working prototypes of climate services to provide climate predictions tailored to the specific requirements of users in different sectors.

To date, the emergence of an industry of climate services has been driven principally by climate information providers, such as national meteorological agencies and climate research institutes (Vaughan and Dessai, 2014). Since the publication of the European Commission's roadmap for climate services (EC, 2015; Street, 2016), it has been clear that it is necessary to strengthen the

provider-user interface. Moreover, our previous experience already indicated that service and visualisation design might contribute to achieving a functional provider-user interface (Davis et al., 2015). To this end we embarked upon an iterative, human-centred approach to develop service prototypes that demonstrated service capability and ensured that design was central to this activity. Design Study Methodology (Sedlmair et al., 2012) was used to guide this process. Initial aims were to have the end-user at the centre of the development engaged in co-design and co-creation of the prototype climate services through a range of participatory approaches (Sanders, 2002). By fostering interdisciplinary teams, design researchers provided new perspectives to the climate services research community. The result of this work is the EUPORIAS visualisation interface, Project Ukko, which provided seasonal wind speed predictions for decision makers in wind energy.

We present our experience in EUPORIAS and Project Ukko to describe the key steps in the development of the EUPORIAS climate services prototype tailored to the specific requirements of users and illustrate how design can contribute to overcome the challenges entailed in the development of a climate service – primarily domain and informational challenges.

2. Design challenges in climate services

This design study identified and described two major design challenges for climate services: a domain challenge and an informational challenge. These challenges emerged in the early scoping stage of the research, and were prioritised through engagement with stakeholders.

2.1. Domain challenge

The primary domain (or sectoral) challenge in climate services is to make innovative information and services useful and usable in a complex landscape of users that are unknown or hard to access and for a not yet established market (Buontempo et al., 2014). The objective of this research was to stimulate a currently embryonic climate services market. The climate services science domain is new and its application in the industry sector is still emerging. As a consequence, many factors may be unknown, such as users and their decision framing and decision-making practices, use cases, tasks, and data.

Climate services need to meet users' needs, capabilities and decision framings (Vaughan and Dessai, 2014). Collaboration with potential users from an early stage of the design process, and a human-centred design approach, can lead to products and services that are usable, useful and likely to be used (Earthy, 2001). The design process – through ongoing user engagement, requirements gathering, a focus on user experience, and user-centred evaluation – can contribute to a thorough understanding of users, tasks and environments to inform product or service development.

The EUPORIAS project developed five prototypes. The prototype that was selected as the most suitable for further development in collaboration with a designer is the RESILIENCE prototype, named Project Ukko, presented in this paper. While developing the EUPORIAS prototypes, potential use cases were unknown, and there was low awareness among relevant industries regarding S2D climate predictions. Potential users were consequently hard to access, motivate and engage. Moreover, the quality (or, more generally, the *skill* attributes) of the predictions can be uneven and in some cases low (Brunet et al., 2010; Weisheimer and Palmer, 2014). This can present a barrier to engaging potential end users, who face pressures of time and cost/benefits balance, and so remain sceptical to participate in a process when benefits to them may be unknown, poorly demonstrated or remote

(Bruno Soares and Dessai, 2016). This presented a challenging problem in the design process; the objective and readiness level created a requirement to develop the problem space and the solution space at the same time.

2.2. Informational challenge

The primary informational challenge in climate services concerns the probabilistic nature of S2D predictions. Ensemble based predictions such as seasonal predictions are probabilistic in nature, meaning that they give the probability of occurrence of certain outcomes, as projected by the model, rather than deterministic, single future prediction. In other words and using wind energy as an example, a seasonal wind speed prediction can be provided as the percentage of probability that the wind speed in the next season will be lower, equal or higher than normal.

Another informational challenge in climate services is the requirement to communicate and present complex scientific information to decision makers in industry. To popularise and broaden the use of climate services and to realise wider impact it is necessary to spread innovative information and products beyond the community of developers and engaged users. Because of its probabilistic nature, climate predictions are often perceived as untailored, unintuitive, hard to understand, and thus difficult to apply in a decision making context, particularly taking into account the varying levels of expertise among users (Bruno Soares and Dessai, 2016; Dilling and Lemos, 2011).

Many sectors, including the energy sector, have entrenched habits linked to the operation of information systems that do not entail managing scenarios (i.e. a probabilistic approach). In addition, current practices are usually based on deterministic approaches only taking into account retrospective climatology (Landberg et al., 2003; Sanz, 2010). These entrenched practices could present a hindering factor for using probabilistic forecasts. Limited spatial resolution and the difficulty or cost of accessing information for commercial reasons, could present yet another barrier to the use of seasonal to decadal climate services.

In this context, design and data visualisation are well-established fields with extensive experience in tackling informational challenges. The key feature of visualisation considered here is with respect to addressing the identified informational challenges. Visualisation research in science and engineering disciplines tends to focus on 'utility' and 'soundness', while visualisation in design disciplines goes further, contributing an attention to 'attractiveness,' which can enhance legibility and cognition (Moere and Purchase, 2011; Quinan and Meyer, 2016).

Climate scientists traditionally use graphical visualisation to present climate data, and visualising uncertainty has been a chief concern in the field for the past two decades (Harold et al., 2016; Kinkeldey et al., 2014). However, there is still not enough empirical evidence to confirm how people interpret these visualisations (Spiegelhalter et al., 2011), particularly when the communication crosses to communities without deep expertise in statistics (Taylor et al., 2015). Expertise and knowledge from different disciplines, joined in interdisciplinary teams, is needed for producing visualisation from complicated, uncertain data (McInerney et al., 2014). Climate services can entail presentation of multi-scale relationships between social and physical processes, and so need more than a conventional single discipline approach. In this research, the team transcended the disciplinary bounds and involved also actors from outside academia, such as data artists (visualisers), into the research process (Lang et al., 2012). This process could be characterised as transdisciplinary, where researchers strive to understand the complexity of the whole problem, rather than only those parts that pertain to their main research discipline (Burgin and Hofkirchner, 2017). The design challenge, in summary, was to

design and test with users, services built on probabilistic information in a new and emerging domain.

3. Design Study Methodology in practice

There have been a number of efforts in the design field to develop definitions, frameworks and guidance for conducting design projects. Prominent visualisation design frameworks include the nested model (Munzner, 2009) and the Design Study Methodology (Sedlmair et al., 2012). While the information visualisation field has tended to focus on the technical and visual implementation of design, both of these frameworks include an attention to why is visualisation needed and for what, as well as how is the process achieved.

To address the domain and information challenges inherent in the emerging field of climate services, the Design Study Methodology was adopted to guide the EUPORIAS design process. The Design Study Methodology describes a sequential process, proceeding through nine stages, which are in turn grouped into three phases: Precondition, Core and Analysis (Fig. 1). The process is not linear, but can loop back to any of the preceding stages.

In EUPORIAS the Precondition phase included building cross-disciplinary understanding of the project and domain, identification of promising collaborations, and development of roles in the project team. The Core phase began with problem and task characterisation, before moving on to the design and implementation of the system, and its deployment and evaluation with users. The Analysis phase involved reflection and writing, and, additionally, multiple channels of communication and engagement were opened, with this outward facing validation occurring since the early stages of the project. A distinctive feature in our implementation of the Design Study Methodology was a break or pivot point between the Discover and Design stages (Fig. 1b).

3.1. Precondition phase - problem characterisation with human-centred design

The domain and informational challenges point to a common requirement for success: the service must be usable. In our

human-centred design approach, a usable service is one that is tailored to its users, which underlines the importance of good communication and visual presentation of the climate information. A functional provider-user interface should thus incorporate communication, co-design, co-production and co-evaluation of the services (Street, 2016). This entails involvement of potential end-users throughout the climate services design process in what is usually defined as human-centred design. Human-centred approaches are applied in service design to facilitate the creation of services that are useful, usable, efficient, effective and likely to be used (Earthy, 2001).

In the early stages of the EUPORIAS design study, science partners and potential end users were engaged in a series of service design events and studies. These human-centred and participatory approaches involved the science partners and potential end users, promoting communication and collaboration channels. The activities ranged from design workshops and an event at a digital culture festival to user surveys and a series of interviews. Domain characterisation and identification of promising collaborations proceeded through a series of human-centred steps. Although the process is not linear, but it allows for feedback through iterative loops, we present it in the following text as consecutive steps mapping Design Study Methodology related stages in brackets.

Step 1. Knowledge exchange between science and design (Learn)

The first meeting aimed at knowledge exchange between science and design and was undertaken at the beginning of the project to develop shared understanding of the primary purpose of the project and build understanding among science and industry partners about possible design contributions and constraints. The main achievement of the meeting was the understanding across disciplines of the main issues related to S2D climate services, including the domain and informational challenges described above. In addition, communication of probabilistic predictions behaviour was identified as a basis for collaboration and design efforts.

Scientists, designers and practitioners are all advanced users of data, but have very different problem solving approaches and hence are not necessarily used to the same jargon, methods and visualisations. Designers and data visualisation specialists, for instance, bring to the team an emphasis on usability and aesthetic form, which can be underrated by scientists who are highly trained

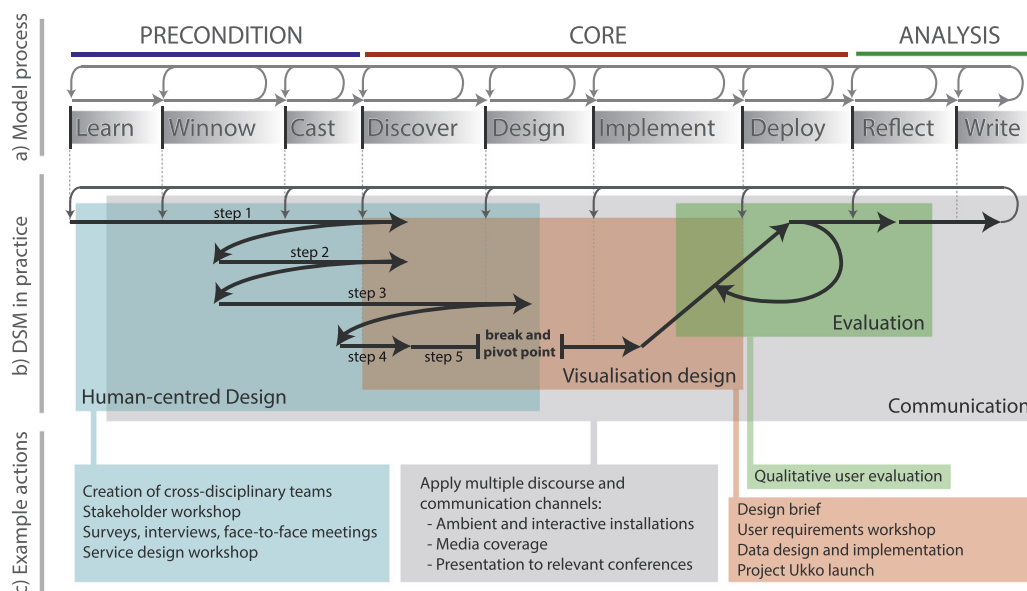


Fig. 1. The Design Study Methodology (DSM) adapted to the development of the EUPORIAS prototypes and Project Ukko. a) Model phases and stages (adapted from Sedlmair et al., 2012). b) DSM in practice illustrating the iterative loops that characterise the design process. c) Main actions performed over the DSM process.

to retain the maximum level of information and detail. Transdisciplinary approaches, however, need clear frameworks of collaboration and sufficient learning time to allow mutual understanding and emerging of real synergies. In EUPORIAS this was facilitated by a history of prior cross-disciplinary collaboration between partners.

This first step enabled the development of shared cross-disciplinary understanding on the domain and informational challenge. It led to definition of the primary objectives for the design component in EUPORIAS: to raise awareness of potential applications of seasonal predictions, and to put probabilistic information into usable form for decision makers in industry.

Step 2. Understand the problem space from an industry perspective (Winnow, Discover)

As there were no well-defined industry users or use cases clearly identified in the early stages of EUPORIAS, an open exploratory approach was needed to examine multiple possibilities and recipients. This first phase, or ‘front end’ of the design process, focused on knowing and understanding the user needs and the contexts of use (Sanders and Stappers, 2012): to explore and select technological opportunities, and to determine what needs to be designed (Sanders and Stappers, 2008; Stappers, 2006).

Workshops were staged with industry stakeholders, to explore the industry landscape and potential applications of S2D climate predictions, and assessed how S2D predictions could inform decision making processes. Furthermore, industry sector participants from agriculture, energy, transport, health and water management, detailed their current practices through a survey and interviews that helped to define possible critical business decisions where application of S2D information could be beneficial (Detailed results can be found at Dessai and Bruno Soares, 2013, 2015).

Step 3. Define the role of design in climate services (Winnow, Design)

A service design workshop was staged to define the role of design, and identify a promising collaboration between one of the climate service teams, a visualisation designer and industry users. The workshop focused on interface design for probabilistic information. The five prototype teams were taken through a structured process to explore how they might work with a designer, learn agile methods and learn how to gather specific requirements inspired by visualisation possibilities. The workshop served to define specific contexts of use and the primary objectives for the EUPORIAS climate service prototypes. This helped the teams to define clear objectives, generate visualisation sketches (provisional designs) and develop high level requirements for visualisation design and implementation.

The management board of the project appointed an external panel composed of three experts to select one prototype for further development. The selection was done using the following criteria: potential impact of this service prototype, clarity of the design brief, and capacity to engage with the visualisation designer. Out of the five prototypes developed within EUPORIAS, the RESILIENCE prototype that provided seasonal wind speed predictions for the energy sector was selected to receive the help of an external visualiser in creating a visualisation tool. We saw high potential for visualisation to enhance the usability of the information by recognised end users – energy traders and wind farm owners – with prospect to impact their activities.

The main outcome of this step was a design brief developed by the EUPORIAS design research team, and an open call to find the data artist to design the visualisation component was launched receiving a large number of tenders.

Step 4. Understand the data, information needs and users capacity (Cast, Discover)

A visualisation design workshop reviewed the primary purpose of the RESILIENCE prototype, the information gap that the climate

services sought to address and the potential contribution of visualisation design to answer the target users’ needs. The meeting defined roles within the cross-disciplinary team that would develop Project Ukko, the visualisation tool for seasonal wind predictions.

This workshop also provided detailed characterisation of the data, as well as the questions to be answered with the data by using the prototype. The RESILIENCE climate service prototype uses data on ten-metre wind speed. These forecast data are obtained from a seasonal prediction system – System 4 – operated by the European Centre for Medium Range Weather Forecasts (ECMWF). The System 4, based on a coupled atmosphere-ocean global climate model (Molteni et al., 2011), produces a forecast using 51 ensemble members. The ensemble corresponds to a group of simulations characterizing climate predictions that are conducted using slightly different initial conditions and stochastic physics. The simulations are produced at the beginning of each month and run for up to seven months into the future.

To evaluate the System 4 prediction quality, the historical predictions of ten-metre wind speed are compared with the reference dataset coming from the ERA-Interim global reanalysis. The reanalysis combines information from discontinuous past meteorological observations with global forecast models to obtain a continuous grid of wind data with no information gaps (Dee et al., 2011). In addition, System 4 seasonal predictions require a post-processing stage for them to statistically resemble the observational reference and minimise forecast errors. Hence, calibration method is used to obtain predictions with average statistical properties similar to those of a reference data set; i.e., to modify the predictions to have the same interannual variance as the reference dataset and correct the underestimation or overestimation of the ensemble spread (Doblas-Reyes et al., 2005).

The consideration of the data alongside the information needs and capacities of users in this step contributed to more detailed characterisation of the problem and task provided by the design brief.

Step 5. Define contexts of use and characterise user requirements (Discover)

The energy sector is at the same time the largest greenhouse gasses emitting sector and one closely related to weather and climate conditions. Mitigation efforts are thus promoting the growth of renewable energies, including wind power (EC, 2014). However, wind energy producers and operators need to anticipate wind resources, their variability at seasonal time scales and their trends over decades. The final user requirements workshop precisely characterised end-users of the seasonal wind speed prediction climate service, defined the questions they needed to answer with this information, and further defined contexts of use. In particular, the participants found that the seasonal wind speed service would be useful for: planning and development, maintenance and investment decisions. This workshop with a focus group of energy users completed the last iteration of the development of Project Ukko and confirmed that it would be used by expert users, including energy traders and wind farm owners, on a recurring basis. This insight led the design team towards adopting a more information-rich and multi-dimensional visual encoding, more apt for expert than lay users.

3.2. Core phase – visualisation design and evaluation

Visualisation design communicates information to users in ways that are effective and also attractive (Daron et al., 2015). In EUPORIAS, during the Preconditioning phase of the Design Study Methodology, visualisation design arose as an opportunity to be applied in one of the five prototype climate services. A design brief was developed following the service design workshop to clearly

articulate the context of use, objectives and success criteria. The brief articulated a central task in EUPORIAS to put probabilistic information into usable form for decision makers in industry.

During the Core design phase, the visualisation designer (Moritz Stefaner) was appointed to work with the design lead in EUPORIAS (FutureEverything) and climate science partners (BSC and Met Office). An interdisciplinary team was created, composed of design researchers and climate scientists, accompanied with a data designer. This provided complementary perspectives to the conceptual design of the visualisation interface for the RESILIENCE prototype climate service.

3.2.1. Visualisation design of Project Ukko (Design, Implement)

The visualisation system developed for the RESILIENCE prototype was Project Ukko (www.project-ukko.net), a user interface aimed at energy traders and wind farm owners. The prototype was developed considering users' perspectives through the steps detailed above. The interface presents a map with seasonal wind predictions visualised in line symbols for around 100,000 regions of the world. The line symbols encode prediction skill through opacity, predicted wind speed through line thickness and predicted trend of wind speed through line tilt and colour (see Fig. 2). This combined data display allows drawing the viewers' attention immediately to those spots with larger probabilities of significant changes in wind speed. The available wind power capacities are also shown in the map, in order to compare future wind conditions with the presence of wind farms. Selecting a point on the map opens a panel with additional information, including the past 30 years of wind observations in the region, the full distribution of 51 prediction results computed from the ensemble members, the detailed skill level as well as the wind power installed capacity (see Fig. 3). The wind power installed capacity presents potential maximum amount of power that can be generated with the existing wind farm capacities in a certain area. The available prototype presented operational predictions for the winter period December 2015 – February 2016.

Seasonal prediction systems, as any other forecast, have to be systematically compared to a reference, preferably observations, to assess their overall quality – this process is known as forecast quality or skill assessment (Mason and Stephenson, 2008). This assessment, based on the performance of the system in the past, informs users about the expected performance of future forecasts (Weisheimer and Palmer, 2014). A particular measure of the predictive skill for the probabilistic seasonal forecast is the ranked probability skill score (RPSS) (Epstein, 1969; Wilks, 2011). The RPSS can range from 1 (for perfect predictions) to $-\infty$. Skill scores below 0 are defined as unskilful, those equal to 0 are equal to the climatology, and anything above 0 is an improvement upon climatology.

To properly read and understand probabilistic predictions it is necessary to, first, highlight skill information to discard information in areas where the forecast doesn't perform well; and second, to view the full distribution of ensemble values. Following the dual objectives identified during the Precondition phase (raise awareness of seasonal predictions, and develop prototypes tailored to end users), the idea of the visualisation team was thus to develop a visual representation of all the members (individual values) of the ensemble prediction, in a way that was attractive and easy to browse and interpret.

Design explorations of the data in the Core design phase, in collaboration between the interdisciplinary team, resulted in development of a visual design vocabulary. To communicate distributions of probabilistic prediction values, a visual metaphor of a cone of rays emanating from the typical (median) value of the historic data was designed using the x axis as a time line from the past (left) to the future prediction (right). This visual device, termed “probability cone”, informed the subsequent development of a coherent visual language for the whole project (see Fig. 3).

A first interface prototype was produced early in the design stage, which allowed experimentation with different glyphs – multidimensional graphical characters – and map designs in a rapid fashion, to understand which shapes and encodings were easily understandable, readable and visually interesting. Further refinements in understanding of problems and tasks took place after the handover to the visualisation designer through the iterative loops in the Discover, Design and Implement stages of the Design Study Methodology.

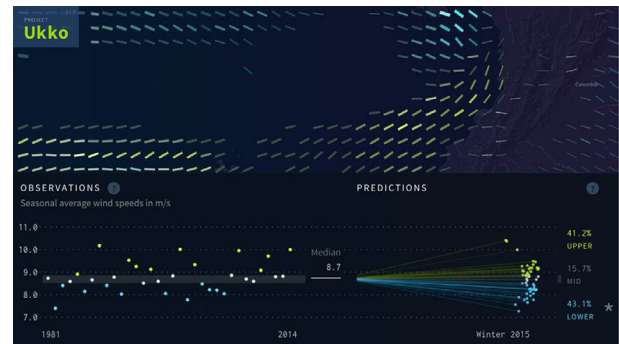


Fig. 3. Main elements of the Project Ukko data visualisation. Above there is the map showing the overview data, and below is the detail information that pops up on demand when the user clicks on a point in the map. On the left there are the historical observations, and on the right there is the “probability cone” showing the predictions for the next season.

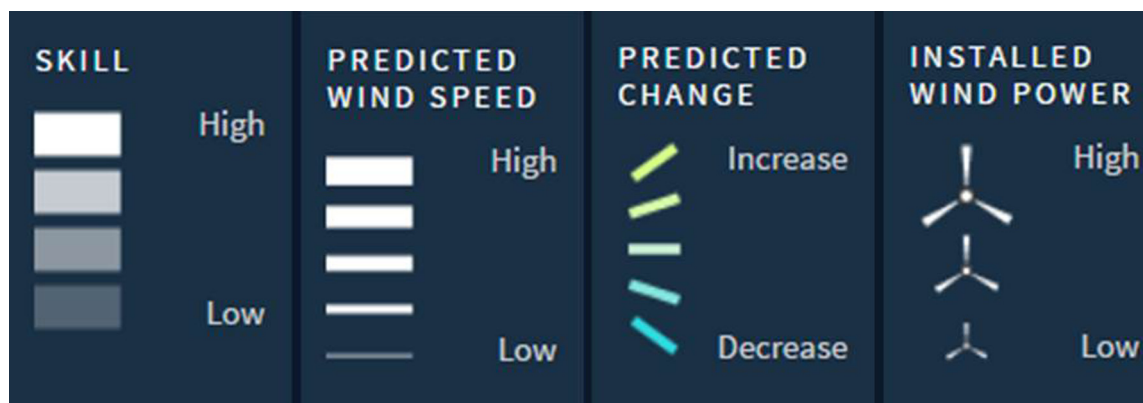


Fig. 2. Legend of symbols used in the Project Ukko data visualisation.

The next challenge in the visual design of the interface was how to present the large amount of information and its variability. For a user to make sense of the probabilistic forecast information, one has to know that the central tendency of the predictions is expressed by how many of the prediction ensemble members fall into the top, middle or bottom third value range of past observations ('terciles'). However, all this information would not be effectively visualised on the world map, as the degree of detail would clutter the view. Thus, glyphs summarised different parameters in a single line, based on an aggregate of the predictions for each location (see Figs. 2 and 3). The three main parameters were presented in the following way:

Predicted trend category of wind speed was encoded in line tilt and colour. Yellow lines pointing to the top right indicated a high probability of increased winds, blue lines pointing bottom right, a high probability of reduced winds. By encoding the predicted trend redundantly in tilt and colour the most important variable is reinforced. Furthermore, tilt and colour complemented each other as colour provides a good overview of trend in zoomed out views, while tilt gives a more precise reading in closer views.

Predicted wind speed was encoded through line thickness. The line strength was directly proportional to the median predicted wind speed.

Prediction skill was expressed through opacity. Regions with higher skill values are more opaque and regions with lower values are more transparent. In order to facilitate readability, the opacity values were binned into 4 discrete steps based on the quartiles of the skill distribution. While opacity is one of the best possible visual encodings for uncertainty (Kinkeldey et al., 2014), it still interferes with the reading of colour and thickness values, thus hindering users' capacity to read parameters in regions with lower skill. In our case this was a desired side-effect as it draws visual attention to areas on the map with good skill levels and low uncertainty, facilitating pattern detection and reading of significant features even at the global scale.

Following the well-known visual information-seeking mantra of overview first, zoom and filter, details-on-demand (Shneiderman, 1996), the full distribution of probabilistic values was still shown in a separate window when the viewer clicks on an individual location, i.e., when a glyph on the map is selected. Compromises between computing and domain specific ambitions are common in design visualisation (Sedlmair et al., 2012). Representing probabilistic information with single values entailed a compromise between science and design communication needs. This compromise, resulting in the information presentation in a clear and simple way, is expected to enhance usability of this service in decision-making.

3.2.2. Design evaluation (Deploy)

Throughout the project, evaluation of the prototype and reflection on the design suggested changes and informed next design steps. This took the shape of informal, formative evaluation involving semi-structured interaction and reflection.

In visualisation design, it is advisable to make a detailed evaluation with a subset of users to review the usability of the tool, detect possible problems early and suggest changes that should be implemented before the large dissemination of the product (Roto et al., 2009). Accordingly, a more formal user evaluation was undertaken with five potential users from the wind energy industry sector, in the Deploy stage, which forms a part of the Core phase of the Design Study Methodology.

The five users selected for testing the prototype were participants with industry profile identified and recruited through the EUPORIAS project network. All participants stated that either they,

or their end users/customers, had an interest in using digital tools to make seasonal wind predictions. The participants were:

- P1 – R&D manager for a consultancy firm providing services to the wind industry.
- P2 – reseller of energy forecasts to wind farm developers, currently selling short-term forecasts.
- P3 – employee in energy assessment department for a global wind energy developer and operator.
- P4 – manager at a major renewables company. Makes wind power production forecasts and related budget forecasts.
- P5 – employee in energy resource department of a large utility company. This department analyses wind behaviour data, including observational and prediction data, to inform the design of future wind turbines.

Observing how the participants freely explored the tool allowed us to collect qualitative information critical for understanding the usefulness of the product and its usage and allowed natural interaction.

The evaluation included 20 questions distributed in 5 areas: comprehension of the research, introduction to the prototype, introductory questions, free exploration of the tool and questions focused on participants' perceptions. We asked the potential users to explore the prototype while thinking-aloud performing realistic tasks – i.e., to tell the researcher exactly what they were doing and why, while they were interacting with the prototype. In addition, we asked them questions aimed at probing their understanding of the different aspects of the prototype. Besides evaluating the interaction of the user with the product interface, it was also important to evaluate how well the visualisation covered the information needs of the users in their daily activities. Participants were hence asked what tasks they would like to perform using a seasonal wind forecasting tool and what information they would like a seasonal wind forecasting tool to provide. We also studied their perception about usefulness and user-friendliness of the prototype. Finally, we asked how likely they were to use the prototype in the future.

The general opinion was that the prototype was very easy to use and that seasonal wind prediction demonstrated much promise (Makri, 2015). Several participants used the word 'intuitive' to describe the usability of the prototype. In the user evaluation, the visualisation was fairly well-understood by participants, although some ambiguities came to light when we probed their understanding of the information presented. For example, some users found it difficult to separate the prototype tool from the underlying seasonal prediction data, indicating that the interface didn't interfere with their genuine interest in the information – a positive outcome from the user perspective, in the sense of the motto 'the best interface is no interface' (Krishna, 2015). Then again, in some cases we elicited mixed responses: the participants thought the tool was good, while the seasonal prediction data was perceived not sufficiently reliable. Finally, the users suggested that adding historical performance of the seasonal prediction to this interface would help improving the perceived reliability of the data. In this sense a clear and usable interface will not only ease adoption of the seasonal prediction data, but also add value to the data itself.

More specific suggestions from users were related to additional prototype's functionalities, such as allowing users to set up custom areas of interest and automatically providing them with new prediction data as it becomes available. It was also recommended to label states and other geographical regional boundaries on the map so that the areas of interest could be more easily identified. Some users also had more specific demands; for instance, traders expressed interest to have prices included, and wind farm

operators were interested in an indicator of demand (e.g. temperature), as well as of supply (e.g. wind speed).

3.3. Analysis phase – user engagement and reflection

3.3.1. Multiple channels of communication and discourse (from Learn to Reflect)

In EUPORIAS, engagement of multiple stakeholders and audiences was integral to the design process, and not just a dissemination activity coming at the end. This allowed defining together the problem and the domain spaces, collecting user feedback on an early prototype and finally evaluate the final product. This was a feature in our implementation of the Design Study Methodology that built on an ‘open prototyping’ framework (Bullinger et al., 2011; Hemment, 2015), creating points of contact to various contributors and users at different stages, and entailed multiple ‘channels of discourse’ (Wood et al., 2014).

From an early stage in the RESILIENCE design journey, four audience groups were targeted: energy industry; policy and public; design and digital culture; and the climate services research community. A number of communication channels and artefacts were developed and applied relevant to each audience group, including: a web application, an ambient installation, interactive exhibition modules, media coverage, festivals and conferences, face-to-face meetings, online participation, social media and an explanatory video (some examples in Fig. 4).

To enhance the penetration of the design and visualisation in the users’ decision making processes it is beneficial to carry out a wide ranging engagement and dissemination strategy. Project Ukko was presented in articles at science and design conferences, and a presentation was also given at a high profile climate services event – Adaptation Futures. Media coverage, in general and spe-

cialised media, is a powerful tool to reach potential users that have not been actively involved in the climate service development. Extensive media coverage was generated for Project Ukko across sectors (featuring at the Guardian, The BBC, Scientific American, the Wired and reference design blogs), and there was widespread engagement on social media. To generate further engagement an interactive exhibit for a touchscreen and an ambient installation were presented at the FutureEverything festival and the Information + exhibition, and a conference event on uncertainty was also presented at FutureEverything.

It was centrally important to reach potential users from the wind energy sector, which was achieved by participating in sectoral events, such as fairs, expositions and conferences (e.g. the European Wind Energy Association annual conferences and workshops). By using diverse channels of communication, the work also reached the other target audiences beyond the climate services community.

3.3.2. Discussion of the design process (Reflection)

Our application of the Design Study Methodology is unconventional in a number of ways. Past design studies have tended to assume users and tasks are known and available at the outset. A notable feature of our implementation of the Design Study Methodology is that we were not replacing an existing task. This data did not exist before, and we looked for potential applications and use cases, as a part of a market initiation process. Visualisation only emerged as a focus part-way through a four-year project.

In EUPORIAS the front end of the design journey involved a series of events and studies through which the domain and problem gradually came into focus, as promising questions and collaborations are explored, and ways forward discounted or taken up. The front end of this journey served to achieve shared understand-

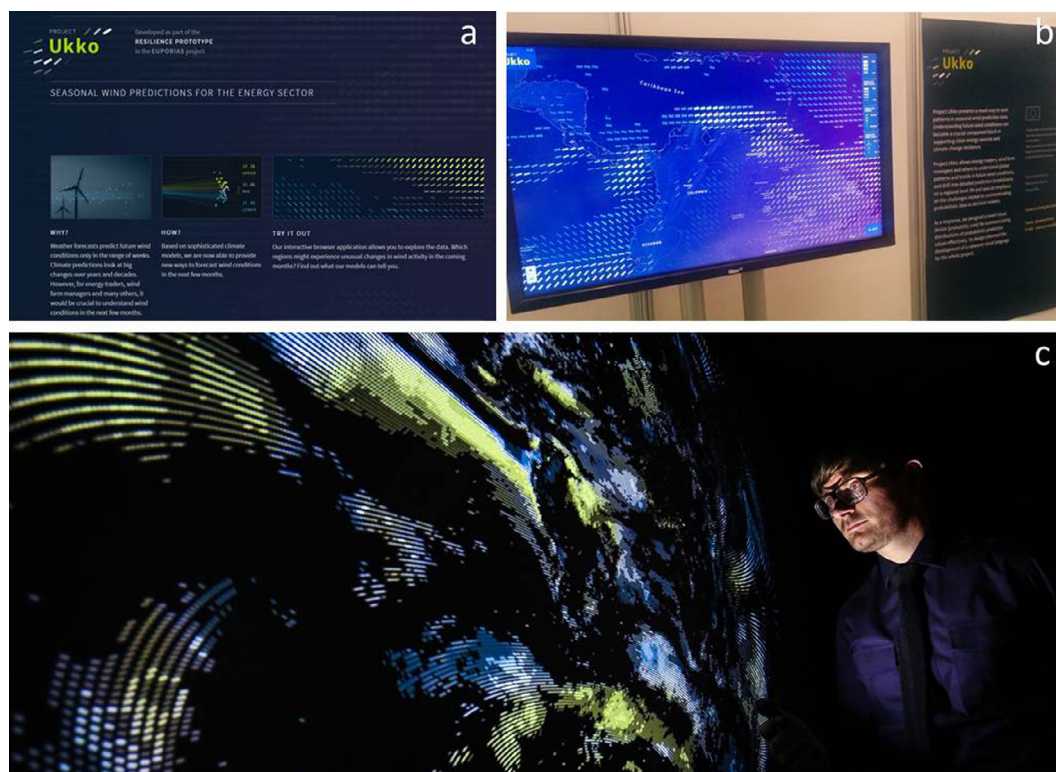


Fig. 4. Examples of communication artefacts to reach different target audiences. a) Web application targeting energy end users, b) interactive exhibition module at Adaptation Futures 2016, targeting climate adaptation researchers and practitioners (demonstration video of the tool is available at <https://vimeo.com/futureeverything/ukko>), c) Ambient installation at FutureEverything Festival, targeting design community (demonstration video of the ambient installation is available at: <https://vimeo.com/moritzstefaner/ukko-ambient>).

ing between science and industry partners about usability of S2D climate services and possible contributions of the visual design. Wide ranging engagement with science and industry stakeholders was required to identify and characterise the domain and the problem. To compensate for this, and address the informational challenge, we developed a well-defined design brief and a handover to a visualisation design specialist, creating a break and pivot point between the Discover and Design stages of the Design Study Methodology.

The long lead in, and extensive domain characterisation, led to the identification and development of an interesting opportunity for a visualisation designer. After the appointment of the visualisation design specialist, a visualisation product was created through an iterative process of design and implementation. Visualisation design supported improved understanding of the nature and structure of seasonal predictions for the energy sector.

We used design to identify potential users, their problems, and where S2D information can benefit decision-making processes. In this respect, front end of the design process can be further characterised as strategic design. Unlike the traditional design approach that often focuses on discrete solutions, a strategic design approach looks beyond these discrete solutions to a systemic “big picture” challenge (Hyde, 2012). In this sense strategic design redefines how problems are tackled, identifying opportunities for action and offering broader solutions, addressing decision-making and anticipating in many cases the user needs (ibid.).

In our implementation of the Design Study Methodology, the learn stage entailed a reciprocal knowledge exchange, rather than an individual’s mastery of a discipline. The cast and winnow stages took place hand in hand, defining the roles and the team, as well as protocols for how they interact. Domain characterisation took place early in the project during the Preconditioning phase and before the pivot point. The Analysis phase involved more than reflection and writing; multiple channels of communication and engagement were opened, and this outward facing validation occurred from the early stages of the project.

This consequently streamlined some of the iterative final stages in the Design Study Methodology.

The design brief, its handover to a visualisation design specialist and the creation of the break or pivot point before the design stage provided clear and consistent success criteria. This consequently created a simplified version of the Design Study Methodology model, with some of the loops in the final stages flattened out (compare the loops in the original model, Fig. 1a, with the applied version of Fig. 1b). The Design Study Methodology assumes access to knowledge, people and resources that were unavailable to us. It also assumes sufficient resources for the many loops. In our case, the challenging process of engaging in an emerging domain made this impractical. The Design Study Methodology model applied in practice – with some loops flattened out—was more feasible for the visualisation designer, and also made the design work ‘smooth’. We posit this was an effective strategy to identify and develop a visualisation project in an emerging domain, or where a full human-centred design is not possible, either due to lack of resources, or when data and users are hard to access.

Another distinctive feature of our implementation of the Design Study Methodology is that, as it happens in many multiyear research projects, EUPORIAS did not involve the same people at the start and the end of the design study. The handovers and pick-ups were therefore crucial. In addition, progressive narrowing of the end user profile throughout the project phases went in parallel with the definition of the scope of Project Ukko. This implicated involving different participants at the beginning and the end of the project.

Due to limited access to data we were not able to meet all requirements identified during the engagement with users. In

addition, due to the complexity of the domain and process, the design journey was not fully developed through co-design, particularly when it comes to presentation of complex scientific information. For instance, the probability cone feature was the outcome of the data and design explorations of the visualisation designer and the rest of the interdisciplinary team. Similarly, glyphs that summarise different parameters in a single line presented a balance between competing needs between science comprehensiveness and design communication, resolved in favour of the high level project communication goal. However, the user evaluation confirmed clarity and usability of this approach.

Based on the comments of the users collected during the testing stage, there are a number of future improvements and open research lines for the visualisation itself as well as for the representation and communication of the prediction and its reliability in an effective way. The first suggestion for the follow-up work is to continue investigating how to present the data visualisation on the map with a critical attitude towards the amount of information included: is it really relevant for users to include as many parameters as possible? Or can we reduce the number of variables displayed in the overview to the ones most relevant for the scope of decisions and decision-making the service is trying to address. The second suggestion is to investigate if there is a more effective way to offer the detail of the probabilities in the forthcoming forecast and its temporal frames: Is this three-month prediction sufficiently narrowed time range? Finally follow-up work should investigate devices that would increase the trustworthiness of the S2D prediction on the target users of the tool.

4. Lessons learnt

The aim of this paper was to share our experience from the implementation of the Design Study Methodology in the creation of the prototype climate service. Lessons learnt from this experience can contribute towards the development of a framework for using service and visualisation design in climate services:

- To stimulate a market for climate services it is necessary to identify in which areas climate predictions can improve decision-making processes and convey the utility of specific services in the effectiveness of users day-to-day work. This entails domain and informational challenges encountered in the creation of climate services. These challenges can be addressed by service and visualisation design in the development of a prototype climate service.
- A human-centred approach can engage the end-user throughout all stages in the design of a climate service, and also other relevant actors in the science, industry and design sectors. In EUPORIAS a variety of user-engagement methods, some conventional (surveys, interviews, consultation), others more novel (design workshops, interactive exhibits, festivals), were used to define the problem and domain spaces, to collect user feedback on early versions of prototypes or to evaluate the final climate service provided.
- Using the Design Study Methodology, we have shown how the ‘front end’ of the design process, or Preconditioning phase, requires sufficient time to encompass extensive domain and task characterization and bridge the gap between the languages of the experts with different fields of expertise.
- In an embryonic market, it may be difficult to elicit requirements for a product that the user may previously not have considered. In this situation of complex domains and emerging markets, this additional attention to the front end of the design journey can help to provide a basis for successful design.

- By creating a well-defined design brief and a handover to visualisation design specialist in the Core design phase, we were able to develop an effective solution putting probabilistic information into an interface that might be used by decision makers. Flattening out some of the loops in the Design Study Methodology model made the project more feasible for the visualisation designer, and also made the design work 'smooth'.
- We posit this is an effective strategy to identify and develop a visualisation project in an emerging domain, or where a full human-centred design process is not possible, either due to lack of resources, or when data and users are hard to access. Acknowledging that most successful design work entails early framing and interrogation of the problem space, we find that such recommendations can be of wide relevance in the development of visualisation design projects.
- The informational challenge in climate services is mainly related to the communication and use of probabilistic predictions as well as differential meaning and interpretation of uncertainty and its uses in decision making processes by users, providers and climate scientists. As one participant remarked in the user evaluation of Project Ukko, "In general, people don't like uncertainties. They like to go to church and listen that if people are good they will go to heaven and if they are bad they will go to hell". In bringing new accessibility to complex and uncertain information, visualisation is a remarkable tool to bridge the gap with end-users and a tip of the iceberg in climate services.
- Visually representing probabilistic information can entail a compromise between scientific soundness, functionality and aesthetics, which in turn requires a transdisciplinary approach bringing together scientists, users and designers. In our experience, interdisciplinary teams need clear contexts of collaboration and sufficient learning time to allow mutual understanding. Given these two conditions, the prototype development team participants in EUPORIAS were taken out of their comfort zones, thus compromises were achieved and real synergies emerged boosting the quality of the outcomes.
- A well-structured dissemination and engagement strategy executed through different communication and discourse channels, as well as direct involvement of potential users in the prototype co-creation, can make more likely the penetration of a climate service in users' decision-making processes. Public presentations, demonstrations and evaluations targeted to the right audience in the right context enable co-creation and testing with a wide range of user groups and can help build the climate services market.
- Due to the complexity and novelty of the climate services field, it is not always possible to meet user expectations or fully answer their needs. Any climate service design should, however, consider and evaluate users' feedback to the greatest extent possible and adopt full co-design as a primary strategy, particularly when it comes to user interface characteristics and additional data and functionalities needed.

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